



Erosive Wear Characterization of Materials for Lunar Construction

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Introduction

Earth's moon is covered in a fine layer of loosely-packed, unconsolidated material called the "lunar regolith". The finest layers, termed "lunar dust", created a number of complications during the Apollo lunar missions of the 1960s and 1970s (Ref. 1). A critical problem caused by the sharp and jagged lunar dust particles was wear (Ref. 2). As the exhaust plumes from the retrorockets of the Apollo lunar module (LM) interacted with the lunar surface, lunar dust particles were entrained into the gas stream and accelerated to high velocities. It became apparent that these fast-moving lunar dust particles can cause erosive wear damage to lunar hardware based on data obtained from the 1969 Apollo 12 mission. Material coupons from the Surveyor III lunar probe, which was located approximately 155 m away from the Apollo 12 LM landing, were returned to earth and extensive analysis, such as scanning electron microscopy (SEM), was performed by Immer et al. (Ref. 3). Immer et al. concluded that surface damage such as pitting and scouring, which are primary erosive wear mechanisms, were indeed caused by the lunar dust impingement during the Apollo 12 landing. As such, the objective of the current work is to provide a quantitative analysis of the damage that lunar dust erosive wear can cause to the candidate lunar construction materials 1045 steel, 6061 aluminum, and acrylic. In this paper, the design of the test rig is presented along with the parameters used in the study. The change in surface roughness is reported both qualitatively and quantitatively for the aluminum specimen.

Experimental Methods

Erosive wear tests were conducted in the Erosion Laboratory at the NASA Glenn Research Center. A Topas Solid Aerosol Generator (Topas GmbH) was used to create an aerosolized stream of the lunar dust simulant JSC-1AF.

The aerosolized dust particles were then accelerated toward the test specimen by a secondary fast-moving air stream. The test apparatus is displayed in Figure 1. The duration of each test was 4 minutes. The particles were accelerated toward the surface at a 90° impingement angle (normal). A dual-disc calibration tool was used to determine that the impact velocity of the particles was approximately 105 m/s. A Zygo 7300 series interferometer (Zygo Corporation) was used to quantify the changes in surface roughness.

Results and Discussion

As an example of the results collected from this study, a qualitative comparison of the effect of erosive wear on the aluminum surface is presented as well as quantitative data on the changes in surface roughness. Though the 105 m/s impact velocity in the current study is moderate compared to the numerical predictions of Lane et al. who estimated particle velocities in excess of 1000 m/s (Ref. 4), the results in the current study represent a less-severe scenario than what may be experienced on the lunar surface. Albeit, even for the moderate impact velocities and short test durations of the current study, the qualitative changes in the optical properties of the surface and the quantitative changes in the surface roughness are significant. For a qualitative comparison, an aluminum specimen before and after testing (in similar lighting conditions) is displayed in Figure 2.

In Figure 2, it can be seen that the surface of the specimen is qualitatively more reflective before testing than after testing. As shown in Figure 2(b), there are two distinct areas on the eroded specimen. The "inner region" was positioned directly under the nozzle in the experiment, while the "outer region" was not.

The results from optical profilometry performed on a fresh aluminum specimen and the eroded specimen, as seen in Figure 2(a) and (b), respectively, are presented in Figure 3 and Figure 4.

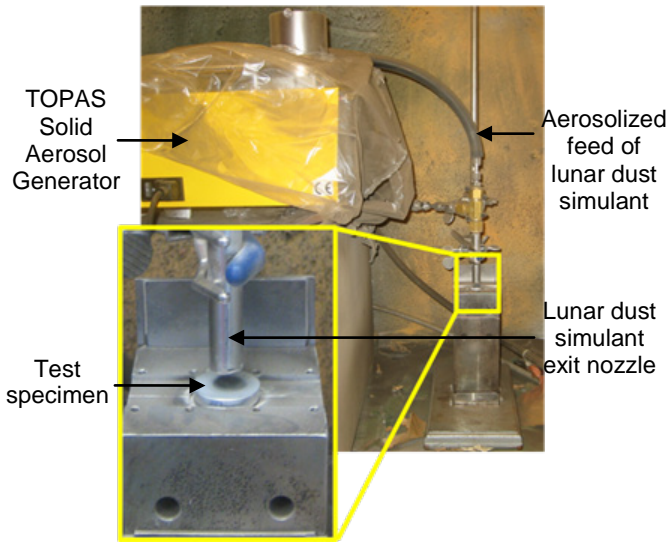


Figure 1.—Image of erosive wear test apparatus

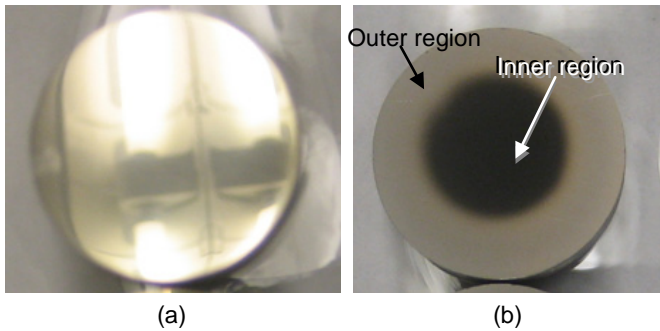
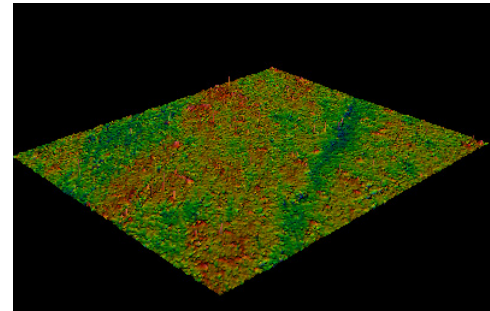


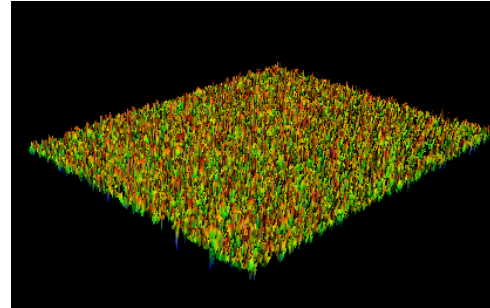
Figure 2.—Image of aluminum test specimen
(a) fresh specimen (b) eroded specimen

It can be seen that the surface of the fresh specimen in Figure 3(a) is relatively smooth compared to the surface of the eroded specimen in Figure 3(b) and (c).

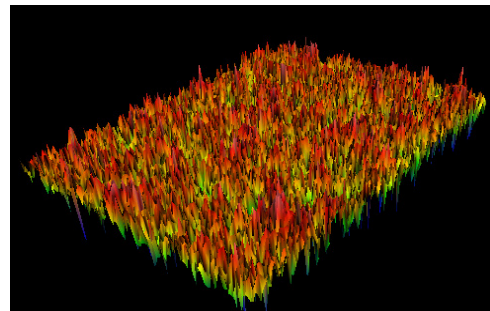
Figure 4 displays a quantitative comparison for the average roughness (R_a) of the fresh specimen from Figure 2(a), and the outer and inner regions of the eroded specimen in Figure 2(b). Interestingly, the outer region, which was not subjected to a direct blast from the nozzle, is about six times rougher than the fresh specimen. This implies that efforts to prevent lunar dust erosive damage on the Moon will need to be robust as even areas outside of the apparent impact area can still sustain considerable damage if line-of-sight is not the only manner for the dust movement. The inner region sustained the most damage and is about 18 times rougher than the fresh specimen.



(a)



(b)



(c)

Figure 3.—Surface profilometry at the same magnification of a 0.35 mm x 0.26 mm area for: (a) fresh specimen, (b) eroded outer region, (c) eroded inner region.

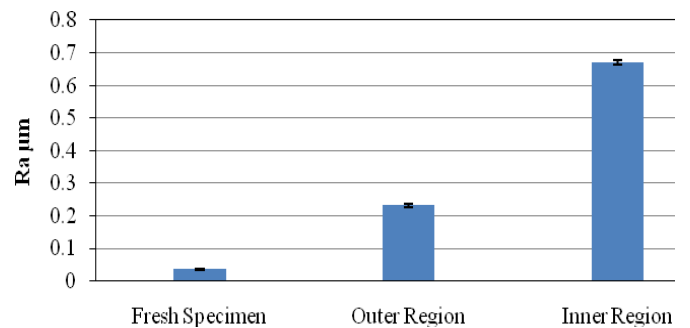


Figure 4.—Quantitative changes in surface roughness due to JSC-1AF erosive wear.

Conclusions

In this work erosive wear tests were conducted using the JSC-1AF lunar simulant. Qualitatively, the surface's optical properties changed as the eroded surface did not reflect light as well as the fresh surface. Optical profilometry revealed that damage due to erosive wear caused an approximate 18-fold increase in the roughness of the surface. Areas of the test specimen not in the apparent blast of the JSC-1AF particles also experienced a significant increase in surface roughness if they are close enough to the source that some exhaust atmosphere is still driving them. This suggests that efforts to mitigate erosive wear damage to surfaces on the Moon may require consideration of the areas outside of the apparent impact region. The results from this study indicate the need for a better understanding of lunar dust erosive wear on critical surfaces of lunar hardware. The changes in surface roughness presented in this work were significant even for moderate impact velocities and short test durations. The high-velocity impacts in lunar conditions and long-term exposure to lunar dust erosive wear may significantly exacerbate the damage. It is believed that the effect of lunar temperatures on material properties may also affect the erosive wear damage and more

research is needed in this area. Understanding erosive wear damage on the Moon is critically important for optical surfaces, such as mirrors and lenses, and thermal surfaces, such as radiators, as their performance can be markedly affected by damage due to erosive wear.

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14. ABSTRACT NASA's Apollo missions revealed that exhaust from the retrorockets of landing spacecraft may act to significantly accelerate lunar dust on the surface of the Moon. A recent study by Immer et al. (C. Immer, P.T. Metzger, P.E. Hintze, A. Nick, and R. Horan, "Apollo 12 Lunar Module exhaust plume impingement on Lunar Surveyor III," Icarus, Vol. 211, pp. 1089-1102, 2011) investigated coupons returned to Earth from the Surveyor III lunar probe which were subjected to lunar dust impingement by the Apollo 12 Lunar Module landing. Their study revealed that even with indirect impingement, the spacecraft sustained erosive damage from the fast-moving lunar dust particles. In this work, results are presented from a series of erosive wear experiments performed on 6061 Aluminum using the JSC-1AF lunar dust simulant. Optical profilometry was used to investigate the surface after the erosion process. It was found that even short durations of lunar dust simulant impacting at low velocities produced substantial changes in the surface.					
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